Paper No. 95-3264
An ASAE Meeting Presentation

EVALUATING THE INFLUENCE OF SOIL TEXTURE, BULK DENSITY AND SOIL WATER SALINITY ON A CAPACITANCE PROBE CALIBRATION

by

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Written for Presentation at the 1995
ASAE Summer Meeting
Sponsored by
ASAE

Chicago, Illinois
June 18-23, 1995

Summary:

A calibration apparatus was constructed for soil capacitance measurements in various moisture, density and saline regimes. Under non-saline conditions there was positive correlation between a calculated Universal Frequency vs. true soil moisture. As soil salinity increased, salinized soil produced sensor moisture values higher in magnitude than true soil moisture.

Keywords:

capacitance probe, bulk density, dielectric constant, soil moisture, soil salinity,

EVALUATING THE INFLUENCE OF SOIL TEXTURE, BULK DENSITY AND SOIL WATER SALINITY ON A CAPACITANCE PROBE CALIBRATION

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Introduction

It is known that soil water content can be measured using capacitance type probes. However, this technique was only experimental until recently when the advent of microelectronics permitted mass production of the probes for commercial use. Essentially, a capacitance probe consists of a pair of electrodes connected to an oscillator. When the probe is inserted into the soil and activated, the soil-water-matrix forms the dielectric of a capacitor which then forms part of an oscillating circuit. The capacitance is measured using a specific oscillation frequency and changes in soil water content cause a shift in the resonance frequency (Dean et al. 1987). This technique is termed Frequency Domain Reflectometry or FDR. It is also known as Radio Frequency (RF) capacitance technique, since radio frequencies of 150 Mhz or more are commonly used (Ley, 1994).

A. M. Thomas (1966) and Hoekstra (1974) found that the capacitance technique was independent of soil type in wide ranges of soil moisture, yet Dean et al. (1987) concluded that capacitance probe readout was influenced by soil type. Kuraz and Matousek (1977) and Whalley et al. (1992) concluded that measurement of soil capacitance was useful in a wide range of moisture contents, yet the measurement can be influenced by changes in bulk density.

Little, if no published research has been done on the interaction of soil water salinity and moisture content on capacitance readings. This paper will discuss the influence of soil texture, bulk density and salinity affects over a wide range of soil moisture using a new capacitance probe, the Sentek* Enviroscan RT5.

Materials and Methods: Soil texture and bulk density calibration

An apparatus was constructed of 30 cm (12 in) diameter PVC pipe which was segmented into four distinct chambers (Fig. 1). Each chamber was 30 cm (12 in.) in height. The chambers were stacked on top of one another to produce a vertical column, such that a 57 mm O.D. (2.24 in.) PVC access tube could be vertically inserted down the center of the chamber-column array. The PVC access tube having a 51 mm I.D. (2 in.), accommodated the Sentek* EnviroScan RT5 probe with attached capacitance sensors. Each chamber was horizontally separated by one sheet of 6 mm (0.25 inch) thick Plexiglas with a 60 mm hole drilled through the center.

*The USDA-ARS does not endorse the product name, but only uses it for descriptive terminology for the benefit of the reader.

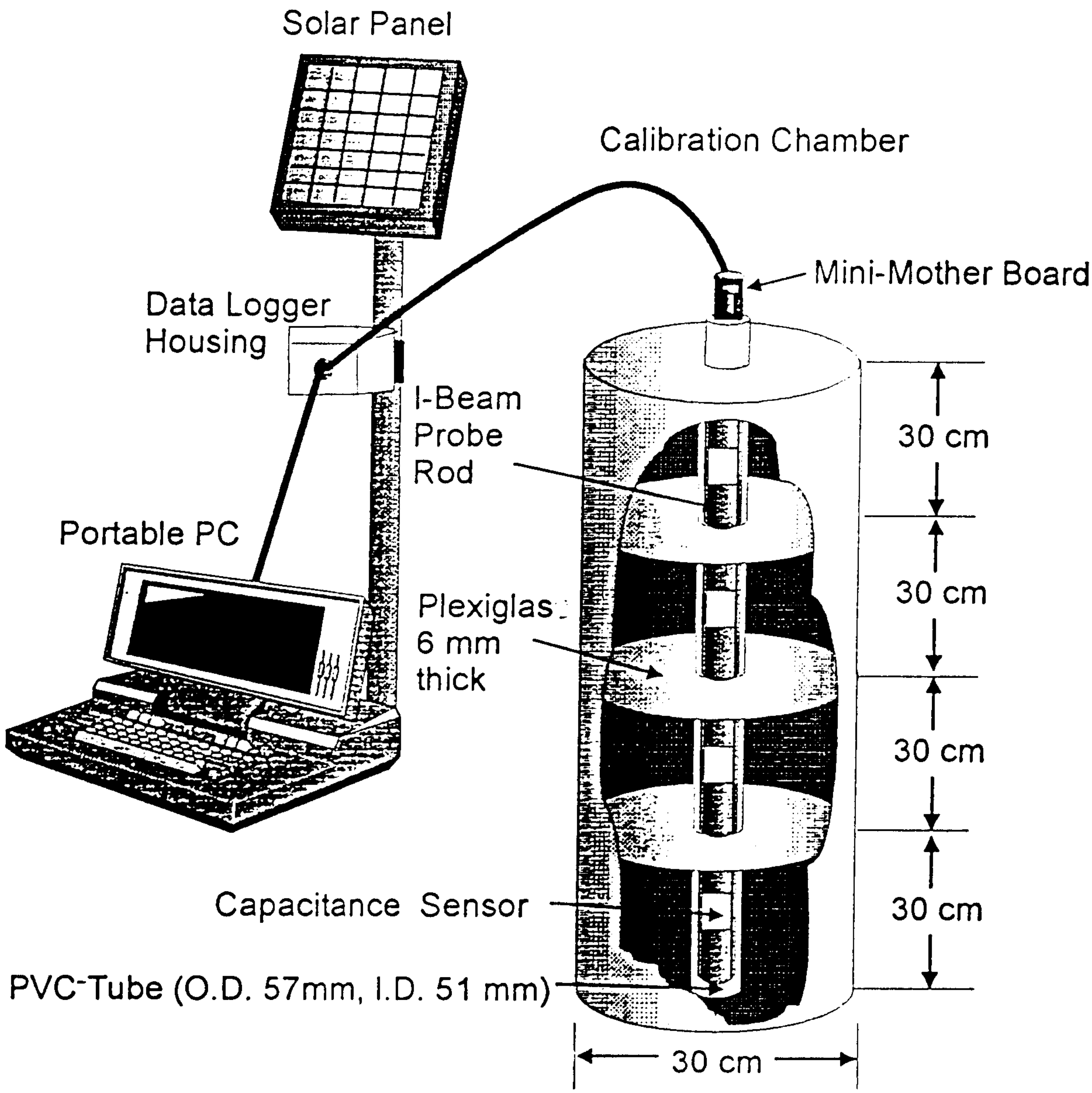

Figure 1. Designated calibration chambers made of 30 cm (12 in.) diameter x 30 cm long PVC pipe, separated by Plexiglas, used to calibrate various soils of different textures, densities and salinity. Direct readings were obtained using a portable PC then transferred to a spreadsheet.

Three soil types were chosen for calibration purposes: coarse sand (100 % sand), a sandy loam (59% sand, 22% silt, 19% clay) and a clay (16% sand, 35% silt, 49% clay). Each soil type was hand packed around the PVC access tube to a given bulk density within each chamber. The bulk density varied by soil type. The sand was packed to a bulk density of 1300 kg/m^3. Due to the more malleable nature of the sandy loam soil, densities of 1300 and 1500 kg/m^3 were created. The clay soil density was established at 1010 kg/m^3. Immediately after all readings were recorded, soil samples were taken with a 135 cm^3 soil bulk density brass ring sampler, 2.5 cm (1 in.) radially and horizontally from the specific capacitance sensor inside each chamber. Soil samples were weighed immediately and placed in a drying oven at 105°C for 48 hours. The samples were then weighed dry to determine volumetric water content.

Various moisture regimes were introduced in the chambers by mixing the specific soil with fresh water thoroughly to the desired moisture content prior to hand packing. The volumetric moisture content for sand ranged from 3 to 15%, from 4 to 35% for the sandy loam and from 13 to 54% for the clay soil. With the exception of the sand, the sandy loam and clay soils were left undisturbed for 24 hours after bulk density and soil moisture levels were created. After 24 hours, raw frequency readings (frequency output) were recorded from the Sentek* capacitance sensor nearest to the center of each calibration chamber. Due to the high hydraulic conductivity of the sand, capacitance data and sand samples were taken within minutes after density packing and specific soil moisture establishment.

Prior to observing capacitance in situ readings for calibration purposes, a normalization procedure was performed such that probe sensor frequency readings were recorded in air, within a normal PVC access tube 1 meter above ground. Then readings were recorded in a barrel of tap water within a PVC access tube to complete the air/water normalization database. This information was used to create a Universal Frequency which is defined as UF = **Fa - F/ Fa - Fw,** where **Fa** represents *air* normalization readings, **Fw** represents *water* normalization readings, and **F** represents in situ probe sensor readings in an access tube in the soil. All in situ readings for calibration were taken with the Sentek* logger/computer interface setup. Air and water normalization frequency readings were recorded on a computerized spreadsheet for immediate calculation of volumetric water content. For calibration purposes, all UF values were plotted against true volumetric moisture content (θ_v) to derive a linear calibration equation for each soil type.

Saline calibration

The sandy loam soil was selected for a specific ***wet*** salinization using saline solutions having electrical conductivity of 0.6, 6, 10, 20 and 38 dS/m, respectively. The saline water was artificially created using equal amounts of NaCl and $CaCl_2$ salt on a mass basis in the solution. ***Wet*** calibrations were performed to establish how soil water salinity affects capacitance sensor readings at or near field capacity conditions. The ***wet*** salinized soil was created by pouring approximately one pore volume of the specific saline solution into a 250 L container of soil and allowed to drain until field capacity conditions occurred (≈35% volumetric water).

Later, *dry* salinized soil using waters of 5, and 20 dS/m were calibrated with the probe sensors to establish if salinized soil affects capacitance readings within wide ranges in soil moisture content. The *dry* saline soil was created by again pouring approximately one pore volume of saline solution into the same 250 L container of sandy loam soil, then allowed to drain and air dry to the desired moisture content (<10%).

Both wet and dry soil calibrations were performed in the same manner as in the textural and density study. Upon sampling, drying and weighing, soils were ground and analyzed for electrical conductivity (ECe).

Results and Discussion: Soil type and bulk density

Based on average of 40 samples per soil type and density, there was positive correlation between the calculated Universal Frequency (UF) vs. true soil volumetric water content (Fig. 2). All intercepts for all soil types were significantly different from one another based on non-over lapping confidence intervals at 95% (Table 1).

The slope for the sand calibration was significantly higher than the other soil types. This could possibly be due to errors in obtaining true moisture data simultaneously with sensor readings, particularly at the wet end of the sand calibration. Had the time delay between sensor readings and sampling been narrowed, a different slope could have been attained. The intercept differences between the sandy loam soil at 1300 and 1500 kg/m^3 bulk densities were significant. Data from the clay and lower density sandy loam (1300 kg/m^3) calibration displayed significant curvature when quadratic regressions were derived. However, under these conditions, R-square values were 0.99 and 0.96 for the clay and sandy loam, respectively.

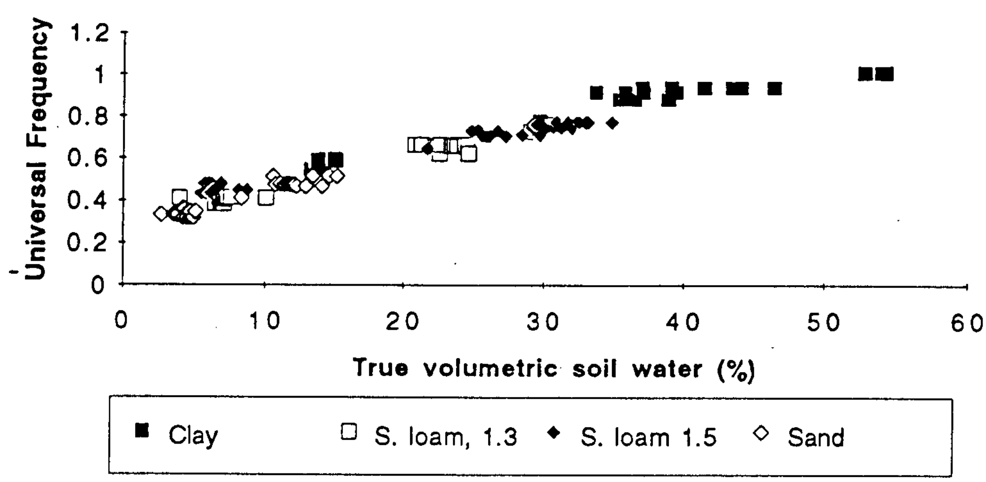

Figure 2. Universal Frequency (UF) derived from capacitance sensors plotted against true volumetric moisture content (θ_v) in clay, sandy loam at 1300 and 1500 kg/m^3, and sand.

Soil type	Density (kg/m^3)	Equation	R-Square	95% Confidence Intervals Intercept	Slope
Sand	1300	0.17x + 0.268	0.987	(0.24, 0.29)	(0.014, 0.020)
Sandy loam	1300	0.013x + 0.326	0.965	(0.31, 0.35)	(0.012, 0.014)
Sandy loam	1500	0.013x + 0.372	0.987	(0.35, 0.39)	(0.012, 0.013)
Clay	1010	0.012x + 0.146	0.979	(0.39, 0.44)	(0.011, 0.013)
Combined soils	n.a.	0.014x + 0.326	0.973	n.a.	n.a.
Default	n.a.	$0.423(x^{0.272})-0.285$	0.968	n.a.	n.a.

Table 1. Calibration equations, R-square values and confidence intervals for three different soil types, two densities within one soil type, and combined soils which plot capacitance probe Universal Frequency (UF) vs. true volumetric soil moisture content (θ_v). Factory default equation is provided for comparison purposes.

Saline calibration observations

The wet saline soil calibration displayed sensor θ_v values higher in magnitude than true θ_v. As the soil ECe increased from 0.6 to 15.4, positively skewed sensor θ_v values were obtained relative to true θ_v. From ECe of 15.4 to 26.3 dS/m, the sensor skewed θ_v values seemed to level off relative to true θ_v. In addition, sensor θ_v values could be artificially lowered by using the same saline water in the normalization setup (water barrel) which salinized the wet soil. Use of 6 dS/m saline water in **Fw** re-normalization, actually gave negatively skewed values below the true θ_v in the 3.4 ECe soil. However, as the salinity of the re-normalizing water increased, the less this lowering affect occurred, particularly past ECw of 20 dS/m. (Fig. 3).

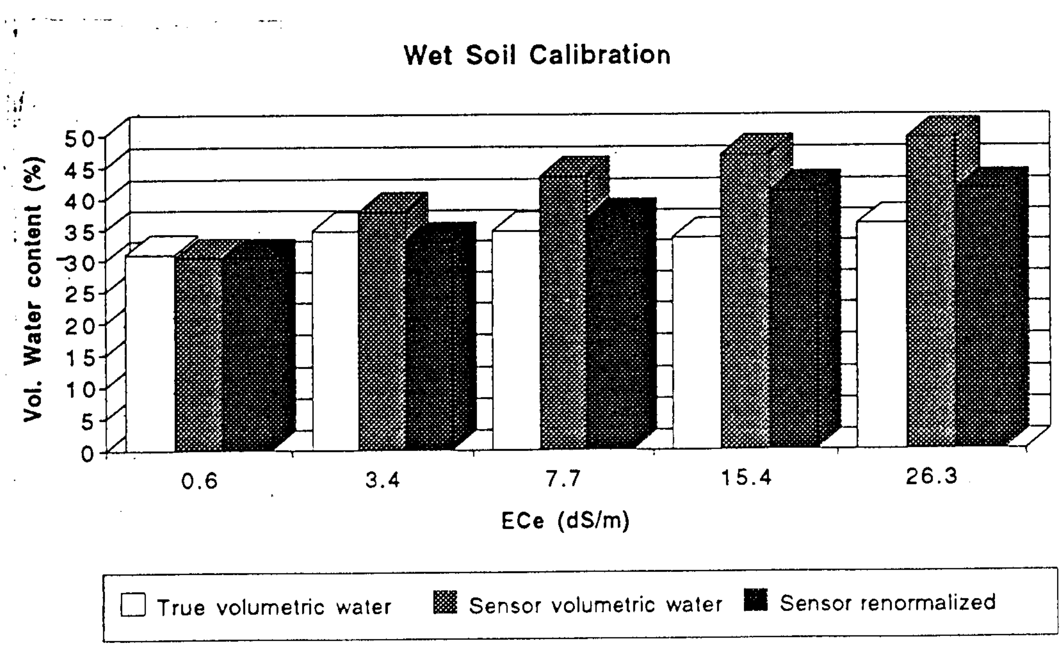

Figure 3. True volumetric soil moisture content (%) and capacitance probe volumetric water content using fresh and saline water for calibration of a wet soil.

The dry saline calibration demonstrated that drier levels of a salinized soil also produced positively skewed sensor θ_v values. Drier soils having ECe of 4.1 and 15.4 produced sensor θ_v values of 67 and 174% higher than true θ_v values, respectively. Consequently, lowered soil moisture in iso-saline conditions produced more increases in skewed sensor θ_v values than with wet saline soil conditions (Table 2). Upon drying, salt ions in the salinized soil probably create increased physical anomalies to the electric field generated by the capacitance probe when measuring the soil dielectric constant. While soil ECe of 15.4 is too high for agronomic production for most crops, soils with ECe of 4.1 are considered moderately saline for some crops and could pose an accuracy problem for calibration purposes.

Using the same saline solution in the re-normalization process (5 dS/m and 20 dS/m water), again lowered sensor θ_v values in similar fashion as did the wet saline calibration. (Table 2). Differences between the reduced skewed sensor θ_v values using 5 and 20 dS/m water was proportional to using fresh water in the normalization process.

ECw	ECe	True Θv	(C.V.%)	Sensor Θv	(C.V.%)	Δ%	Re-norm. Sensor Θv	Δ%
5	3.4	34.7	4.6	38	2.6	10	33	-5
5	4.1	2.5	17.6	3.5	3.4	67	3.1	48
20	15.4	33.6	3.7	46.9	2.6	40	41.1	22
20	15.4	5.7	16.1	15.6	19.1	174	13.5	137

Table 2. Salinity of water to salinize soil (ECw), salinity of soil extract (ECe), true soil θ_v, sensor θ_v values, coefficients of variation(%), and percent difference between true and sensor θ_v(Δ). Also displayed are renormalized sensor θ_v values using ECw in normalization procedure and percent difference between true and sensor θ_v(Δ).

Summary

The significant calibration differences that occurred between soil types and densities within soil type, imply that site specific calibrations need to be performed for the most precise correlation between true θ_v and the Universal Frequency. Choosing the shortest time delay between capacitance readings and sampling in sandier soils will obtain the most precise calibration. Soil salinity will pose a more complicated situation for site specific calibration purposes, especially when measuring wide ranges of soil moisture in very saline soils. Artificially adjusting the Fw using saline water during the normalization routine will help decrease skewed values, but only in moderately saline soils.

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